

---

---

*Panel Discussion*

**Can Cross-Layer Techniques Enhance the  
Performance of Tactical Military Networks**

*Andrea Goldsmith*  
*Stanford University*

**NATO Cross-layer Workshop  
Naval Research Labs  
June 2, 2004**

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>01 DEC 2007</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED	
4. TITLE AND SUBTITLE <b>Panel Discussion - Can Cross-Layer Techniques Enhance the Performance of Tactical Military Networks?</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Stanford University</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited.</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>8</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

# Crosslayer Design: *A New Paradigm*

---

- Hardware
- Link
- Access
- Network
- Application



Delay Constraints  
Rate Requirements  
Energy Constraints  
Complexity Constraints  
Robustness

*Optimize and adapt across design layers*  
*Provide robustness to uncertainty*  
*Use scheduling to reserve resources*

# Special Considerations of a Military Environment

---

- Unique considerations for military systems
  - Low performance radios (10s of Kbps in some cases)
  - Heterogeneous equipment with different capabilities
  - Hostile environment (jammers, node destruction)
  - Applications with very different requirements and priorities.
  - Widely varying communication conditions and network topologies
  - Legacy systems
- Can cross layering addresses these considerations
  - Adaptation and diversity can provide robustness to jamming and node destruction and compromise
  - Cross layering supports different requirements and priorities across all layers of the network protocol stack.
  - Cross layering can adjust higher layer protocols to the capabilities of underlying equipment.
  - Cross layering adapts to and provides robustness against variations in the communication capabilities and network topology.
  - Not clear how legacy systems can exploit cross-layer protocols.
    - Some systems must do crosslayering with constraints on some layers.

# Impact of energy considerations on cross-layering

---

- Each node can only send a finite number of bits.
  - Bit allocation must be optimized across all protocol layers
  - Must use energy per bit as performance metric (not power= $E/T$ )
- Short-range networks must consider transmit, circuit, and processing energy.
  - Circuit and processing energy can dominate energy consumption
  - Sophisticated communication and signal processing techniques not necessarily energy-efficient (e.g. high level modulation, coding, etc.)
  - Circuit energy minimized by minimizing bit duration, transmit energy minimized by maximizing bit duration
    - Leads to optimal bit durations and energy vs. delay tradeoffs
  - Sleep modes save energy but complicate many aspects of networking (synchronization, routing, access, sensing functionality, etc.)
- Changes **everything** about the network design:
  - Delay vs. throughput vs. node/network lifetime tradeoffs.
  - Brings “hardware layer” into the protocol stack

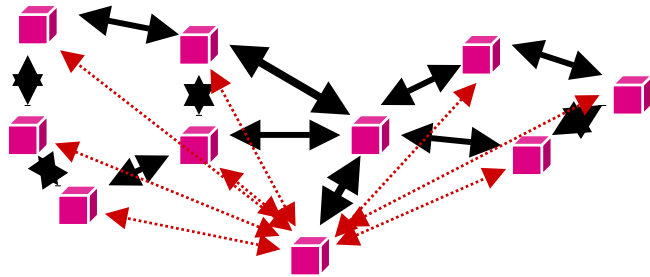
# To Cross-Layer or Not

---

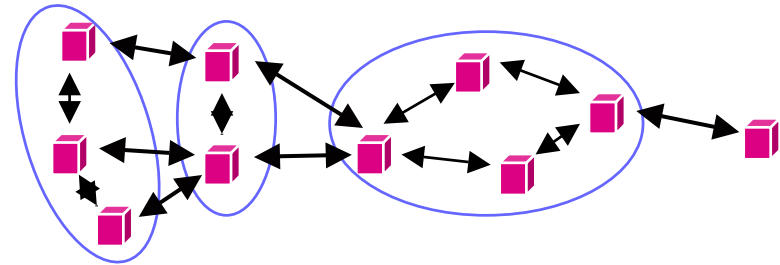
- Layering is not evil
  - Reduces complexity and provides design abstractions
  - Has worked well in the Internet, and is not going away
- Cross-layer design is not about eliminating layers, but about designing across them
  - Gains possible for both wireless and wired networks
  - Some types of networks and applications will benefit more than others
  - Need to determine where significant crosslayer gains are possible
  - Want to avoid negative interactions between layers
- Need to address key questions in crosslayering
  - What is the right framework for crosslayer design
  - What information to exchange across layers, and how to use it
  - How to balance adaptivity, diversity, and scheduling
  - What are the key crosslayer synergies: how many layers to involve
  - How to avoid unexpected interactions across layers
  - How to manage cross-layer complexity
  - How to deal with legacy systems and protocols

# Ad-Hoc vs. Sensor Networks

---



- Peer-to-peer with no backbone infrastructure.
- Nodes often mobile
- Nodes generate independent information
- Can require high data rates
- Typically support multiple applications
- Peak or average power constraints



- Data flows to a centralized location
- Nodes often stationary
- Node information correlated in time/space
- Low per-node rates but 10s to 1000s of nodes
- Typically support a single application
- Energy a driving constraint

# Cross-Layer Gains: Ad-hoc vs. Sensor Networks

---

- Both types of networks can benefit from cross-layer design, but probably sensor networks more than ad-hoc networks.
- Stand-alone networks designed for one dedicated purpose have the most to gain from cross-layer design.
- Ad-hoc networks may be more constrained by existing standards and interoperability, which make cross-layer design more difficult.
- Mobility in ad hoc networks make adaptivity and scheduling difficult, and robustness critical.
- A driving energy constraint, typical in sensor networks, makes cross-layer design imperative.
- Performance gains of an order of magnitude or more in both types of networks are possible.

# Research Agenda

---

- Pursue both broad cross-layer design frameworks and tailored cross layer designs for specific applications
  - We don't have sufficient insight to see big picture yet
  - Just starting to ask the right questions, but don't necessarily know how to answer them yet
- Further explore adaptivity, diversity, and scheduling in a cross-layer context
- Networks with energy-constrained nodes.
  - What are appropriate abstractions, especially for H/W
  - What is the right cross-layer framework
  - How does application layer/compression come in
- Collaborative transmission and signal processing for sensor networks.